A Tunable Artificial Magnetic Conductor Using Switched Capacitance in a Concentric Overlapping Geometry

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1. Introduction

An artificial magnetic conductor (AMC) - sometimes referred to as a high impedance surface - is a lossless reactive surface, usually realized as a printed circuit board, which inhibits the flow of tangential electric surface current. This approximates a zero tangential magnetic field and results in a high equivalent surface impedance over some finite bandwidth [1]. AMCs also have the property that both transverse magnetic (TM) and transverse electric (TE) surface waves are cutoff over some frequency range [2,3]. When properly designed, the AMC surface wave bandgap will correspond to same frequency band where the AMC exhibits the high surface impedance - thus enabling realization of an efficient, electrically thin antenna structure.

One critical limitation on the utility of AMC-backed antennas is that the instantaneous bandwidth achieved is directly proportional to the electrical thickness of the structure. An AMC that is $\lambda/40$ thick will achieve a 3 dB bandwidth of approximately 15 percent. While this may be useful for some applications, there are many more where a broad range of frequencies – possibly, multiple octaves - are of interest. It has been demonstrated that electrically thin structures can be electronically reconfigured for such applications [4].

In [4], varactor diodes were used in series with a single layer FSS-like structure to adjust the net AMC capacitance and hence the resonant frequency. Another method of achieving tuning is to reconfigure the AMC by discretely switching in and out varying amounts of capacitance – in the form of physical overlap of a two-layer FSS - using PIN diodes or MEMs switches. This approach may have advantages in power handling over the varactor case. Also, because a two-layer FSS geometry can obtain very large capacitances per unit area, this approach may also yield a significantly higher tuning range versus the varactor approach. This paper describes analysis, design, fabrication and test of such a structure.

2. Concentric Loop Concept

Figure 1 shows a tunable AMC design based on the switched capacitive overlap concept. The bottom layer of the FSS consists of contiguous square patches, and the upper layer is a series of concentric square loops, each having different surface area. The loops are segmented into four parts with surface mounted

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switches bridging the gaps between each segment. The switches are used to change the density of the overlapping printed patches by turning each loop in a unit cell "on" or "off". The result is 2^N tuning states for an N-loop geometry. The vias, indigenous to the high-impedance surface, can be used to route bias currents and voltages from stripline control lines buried within the RF backplane.

3. Analysis and Design

Figure 2 shows a simple equivalent circuit model that has been developed for quick optimization of the AMC tuning states. This model replaces the simple capacitance used for conventional FSS structures, with an equivalent circuit that is more representative of the multi-loop geometry (includes the necking inductance of the thin loop arms as well as the equivalent circuit parameters of the switches). Rigorous full-wave tools such as Sonnet's Microwave CST or Flowmerics' Microstripes can then be used to refine the design prior to fabrication and test. The specific design of the loop configuration is typically customized for any given application, with contiguous or non-contiguous frequency coverage for sequential design states as required.

3. Proof of Concept Fabrication and Test

A set of AMC ground planes was fabricated and tested as a proof-of-concept. In order to simplify this initial experiment, we chose a three-loop design where switches were implemented with physical shorts or opens. This necessitated separate fabrication of individual states. We realized four of the eight possible states in order to demonstrate the tuning range and capabilities of the design.

Figure 3 shows a picture of the AMC surface for the "State 2" configuration. Also shown in the figure are the simulated and measured reflection phases for each of the realized states. Discrepancies between simulations and measurements are attributed to parasitic capacitance associated with finite metal thickness that is not incorporated into the model. Surface wave measurements were also performed for each state. Figure 4 shows a picture of our surface wave measurement set-up. In this set-up an S21 measurement is performed between two horn radiators oriented so as to excite TE or TM modes on the AMC surface. Absorber is placed around the surface-under-test to minimize the space wave coupling between the antennas. Also shown in Figure 4 are the TE and TM surface wave measurements for AMC configuration state 2, demonstrating good alignment of the high-impedance and surface wave bandgap. As the loop configuration was altered (i.e. "tuned") the surface wave bandgap tuned in frequency along with the high-impedance band.

4. Summary

In this paper, a new method for reconfiguration of artificial magnetic conductors has been described that uses a switched capacitive overlap in a concentric loop geometry. A simple circuit model has been developed for rapid iteration that agrees well with the rigorous full-wave solution for reflection phase. The concept has been successfully demonstrated in a geometry that exhibits more than 3:1 tuning bandwidth. A practical limit of 5:1 or 6:1 bandwidth is possible (depending on operating band and practical limitations of the PIN diodes or MEMs switches). The frequency bands for the high-impedance and surface wave bandgap have been demonstrated to maintain alignment as the structure is reconfigured.

5. References

[1] D. Sievenpiper, "High-impedance electromagnetic surfaces," Ph.D. dissertation, UCLA electrical engineering department, filed January 1999

[2] Diaz, R. E., J. T. Aberle, W. E. McKinzie, "TM Mode Analysis of a Sievenpiper High-Impedance Reactive Surface," *IEEE Ant. and Prop. Intl. Symp*, 2000. IEEE, Volume: 1, 2000, Page(s): 327 -330

[3] Diaz, R. E., J. T. Aberle, W. E. McKinzie, "Analysis of the Surface Wave Suppression Band of the Sievenpiper High-Impedance Ground Plane in Terms of its Effective Medium Properties," *National Radio Science Meeting*, January 8-11, 2001, University of Colorado at Boulder, Colorado.

[4] Sanchez, V.C., R. E. Diaz, and W. E. McKinzie, "Broadband Antennas Over Electronically Reconfigurable Artificial Magnetic Conductor Surfaces", *Antenna Applications Symposium*, September 19-21, 2001, Robert Allerton Park, Monticello, Illinois

6. Acknowledgement

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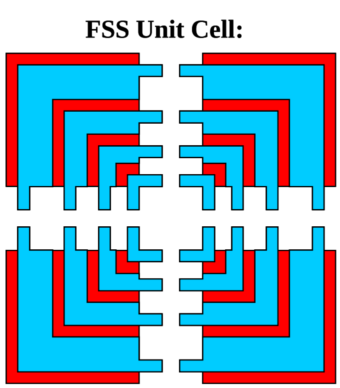

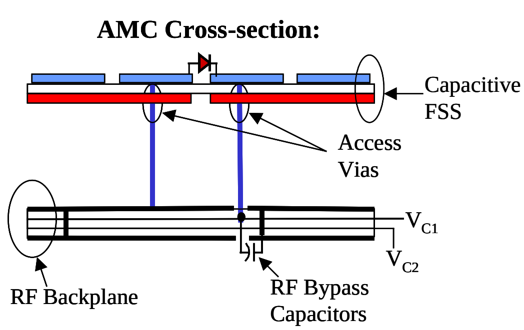

Figure 1 - FSS unit cell & AMC cross-section showing bias via configuration

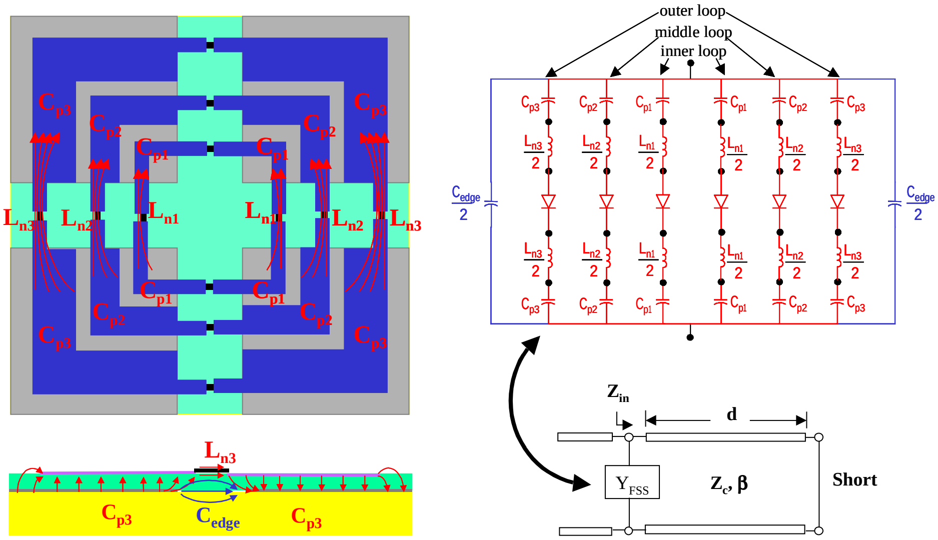

Figure 2 - Multi-loop FSS Geometry and Equivalent Circuit Model

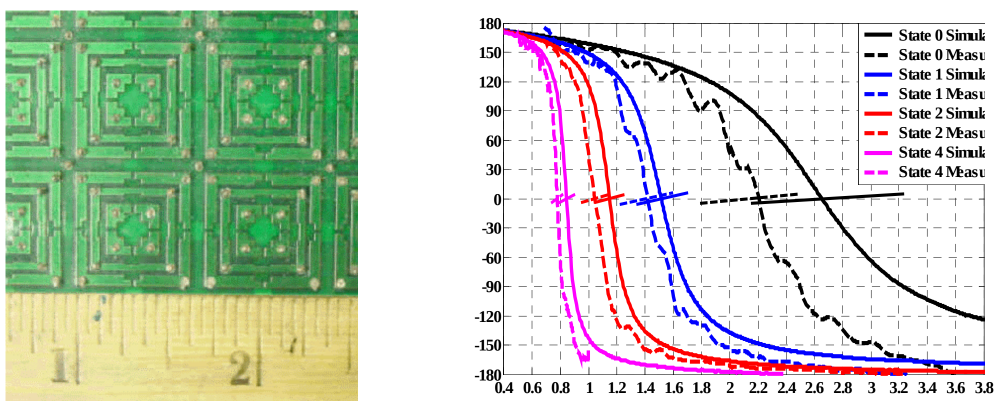

Figure 3 - AMC State 2 Geometry and Reflection Phase for Each State (Measured & Predicted). The ±90° bands are indicated by the slant line

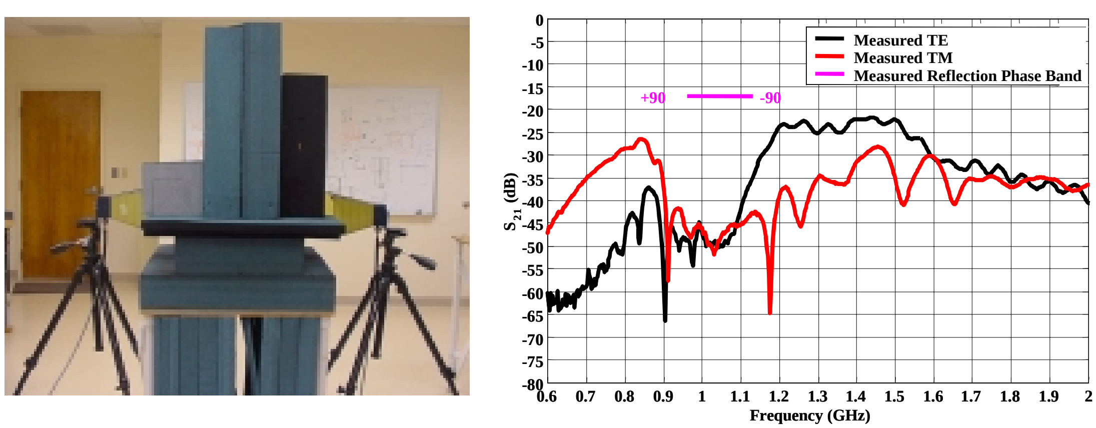

Figure 4 – Surface Wave Test Set-Up and Measurement Results